PEC673 - Master of Science in Environmental Architecture

Solar Passive Architecture as a Design Element for Residential Houses in Nasik, India

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Dissertation Report 2012

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Abstract

There is an urgent need to conserve energy due to the depletion in its natural reserves and escalating prices. Architects, engineers and planners play an important role in creating the built environment. So, it is time they start designing energy saving, climate sensible, solar passive human habitat. Thus, the primary objective of this research is to produce some guidelines for climate sensible architecture and design solar passive elements for houses in Nasik, India.

In this research, understanding of different types of solar houses has been demonstrated. Climatic data has been collected for Nasik and accordingly the solar passive principles are applied for the houses of Nasik. To enhance the aesthetic appearances of the building, few solar passive elements have been designed in this research and their effectiveness is tested by Tecto-hand calculations. The outcome of this report can be used by Nasik's architects and planners as a design manual for planning solar passive houses.

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1. Introduction

The beginning of what may, in the present context, be described as 'unsustainable' architecture began, at the end of the 18^{th} century, with the industrial revolution, when more and more technologies were incorporated into the building fabric. In order to operate these technologies, energy and natural resources are consumed on a large scale leading to the depletion of resources (Brown and Dekay, 2001). Due to the ever increasing demand, natural gas and electricity is becoming increasingly expensive, leading people to explore ways of performing the same task without wasting energy. Now-a-days more than half of the energy consumed, is for heating or cooling spaces. The use of solar energy to control temperature can be extremely economical in comparison.

Solar energy can be controlled in many ways which can help in minimizing the use of mechanical and electrical heating or cooling. Some of these methods are inherent in the design of architectural elements of the building, which can be designed to minimize the building's solar gain for cooling or maximize for heating, depending on the climatic conditions. However, often they are difficult to combine logically, so a choice must be made to use the most efficient and appropriate systems.

Solar passive architecture designs are based mainly on simple planning concepts such as orientation, placement and shading of windows, type of materials, color of finishes and landscape among others, to build up spaces that generate comfortable indoor conditions. These techniques affect the building envelope, which not only act as a thermal barrier between the indoor and outdoor spaces, but also help significantly in determining how effectively the building can make use of the natural lighting, natural ventilation and heating and cooling resources. Therefore, to minimize the level of discomfort and to reduce the use of mechanical energy to maintain comfortable thermal conditions, intelligent use of solar passive elements and molding of the built form is required (Nayak, Hazra and Prajapati, 1999).

In this research, I have explored and designed some solar passive architectural elements, for the temperate climate of Nasik – a city in the west of India where I live - elements that are considered to be the most effective at keeping the indoor atmosphere comfortable. The effectiveness of these elements is tested through Tecto hand calculations.

1.1 Background

The demand and consumption of non-renewable energy resources are vast and ever-increasing. But they are finite in nature and will extinguish soon due to their increasing demand. The total energy consumption pattern can be divided into three sectors namely, industrial, transportation and buildings, where buildings consume approximately 50% of the total consumption (Gissen, 2003). It is ascertained that the maximum amount of energy is used to maintain thermal comfort levels and provide a luxurious lifestyle for the occupants (Mathur, 2008).

The vast consumption of electricity in India has lead to an increase in energy prices. A common man’s worry is not about the finite resources but, the heavy bills he needs to pay for his comfort. This has made the people in India to turn towards energy-efficient housing, which can provide thermal comfort with the consumption of least amount of energy. Even from an aesthetic point of view, solar passive architectural elements add an extra dimension to the built form, enhancing the visual quality and living standards. In temperate climate like Nasik, the ‘Sun’- renewable, nonpolluting, abundant and direct source is present for the major part of the year. It is necessary for building design to control and utilize this abundance, that is block out the solar access in summer and ensure access in winter (Vyas, 2005).

1.2 Learning Objectives

Indian Architecture is known for depicting its unique culture and traditions from its designs. The ancient science of design, “Vastushastra” is still a strong guideline in this modern age, for architects practicing in India. But now-a-days, due to the ever-growing population and space constraints, cities have started developing vertically and also have increased the consumption of energy. As a result, cities in India have to suffer from load-shedding for hours together every day due to limitations of energy supply. There is an urgent need to cut down on consumption of energy to overcome this problem (Mathur, 2008).

Nasik, a developing city in the western part of India, is no different from other cities in the country. It also has to suffer from load shedding problems due to shortage of electricity supply. Thus, the primary objective of my research is to endeavor to produce guidelines for climate-sensible, solar passive house designs for the city of Nasik that can help in reducing the energy consumption of houses and provide comfortable living conditions. At the same time, I want to incorporate traditional Indian Architecture in my designs. These elements will be designed to be easily incorporated in any type of structure for the climate of Nasik as well as for locations in similar climatic conditions in India.

1.3 Research Method

The objectives of this dissertation were achieved by a deductive approach of analysis, designing and testing. Distinctively it includes:

- The climatic analysis for Nasik, on the basis of data provided by the Nasik Meteorological department
- A Study of the concepts of active, passive and hybrid solar passive architecture.
- The Concepts of solar passive architecture applied in accordance with the local conditions of Nasik.
- The designing of architectural elements for solar passive architecture applicable to any house design for Nasik.
- The application of a few of these elements to a house and to test the performance with the Tecto-hand calculations.

1.4 Location

Figure 1: Map of Nasik, India

(Image source : http://www.wodenrotary.org.au/customdata/index.cfm?fuseaction=display_ main & ItemID =49165&OrgID=8118)

The City of Nasik is a landlocked city in the State of Maharashtra, which lies in the western part of India. It is approximately 220kms from the business capital of India – Mumbai. Mumbai is also the closest coastline to Nasik. Its main latitude and longitude are 20º02´N and 73º50´E respectively. It is situated at an altitude of 565 m from mean sea level (Gaisma, 2012).

Nasik is almost uniformly flat in topography. It is situated on the edge of the Deccan plateau, which is entirely a volcanic formation. Generally, black cotton soil is found in this place which is washed down by the rains from basalt rocks.

It covers a total area 15,530 sq.m. and holds a population of 1,629,769 according to the census of 2011. Due to rapid urbanization of this city, it has become one of the fastest growing cities in India, attracting a number of investors from around the world. It is also known as the “Grape City”, as it produces good quality of grapes. Following the production of grapes, there are around 48 wineries in its jurisdiction, making it the “Wine Capital” of India (Official website of Nasik, 2012).

In the next chapters of this thesis, I have studied different types of solar housing strategies and designed ways for their integration in the houses in Nasik.

2. Concept of Solar housing

We need to first understand the concept of Solar Housing to design solar passive strategies for the houses in Nasik city. In general, a solar house can be described as a house where most of the energy needs are satisfied by sunshine, cool breeze and warmth of the sun, which reduces other energy costs by 40-60% (Nayak, 2010).

A solar house which is fitted with a highly efficient heating system can fully satisfy the space heating needs and lighting needs even without the use of other energy sources. It also reduces the worries of blackouts and power outages, problems of wires from outside and the pain of piling up a stock of wood, coal or fuel oil. Energy costs can be further reduced by the installation of photovoltaic systems to provide electricity and also solar water heater can contribute to the savings by fulfilling hot water needs. The solar systems can also add an architectural feature to the building and enhance its aesthetic appeal (Gissen, 2003). The use of solar energy for housing to reduce the dependence on non-renewable energy resources can be achieved through active, passive or a combination of these means.

2.1 Active solar house

In active solar houses, the heating and cooling of spaces are achieved by active mechanical engineering systems that are designed to collect, convert, store and distribute solar energy. The mechanical systems used in these kinds of houses are actually places separate from spaces which need heating or cooling. They are formed by the combination of many component parts mainly, solar collectors for collection of solar energy, pipe or ducts for distribution, rock beds or water tanks for storage, pump or fans for mechanical distribution and control devices to control the working. Compared to passive solar systems, the installation and maintenance of these systems can be complex and expensive. These systems consume a certain amount of conventional energy to run the mechanical pumps and fans. Active solar systems can be controlled directly by the occupants for required level of heating and cooling of spaces (Badescu and Staicovic, 2006).

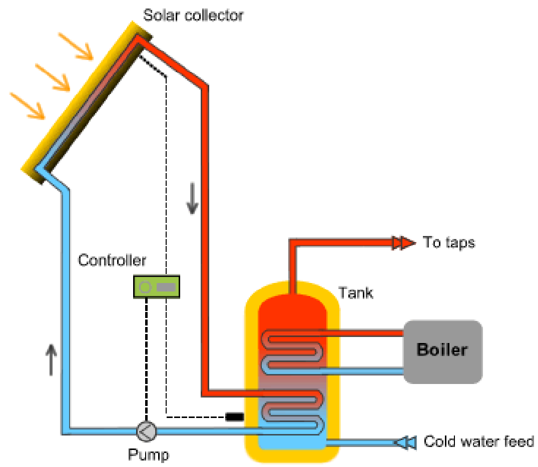


Figure 2.1: Active solar water heater system
Source: http://www.daviddarling.info/encyclopedia/A/AE_active_solar_energy_system.html

2.2 Passive solar house

The basic concept of a passive solar house approach is to maximize the solar gains and minimize their losses. This can be achieved by increasing the energy efficiency of the basic building components like the roof, floors, windows and shading devices. It is also necessary to design the building services like electrical and plumbing appropriately to achieve maximum energy efficiency. By using this kind of system, the mechanical systems are not needed to be used, which saves

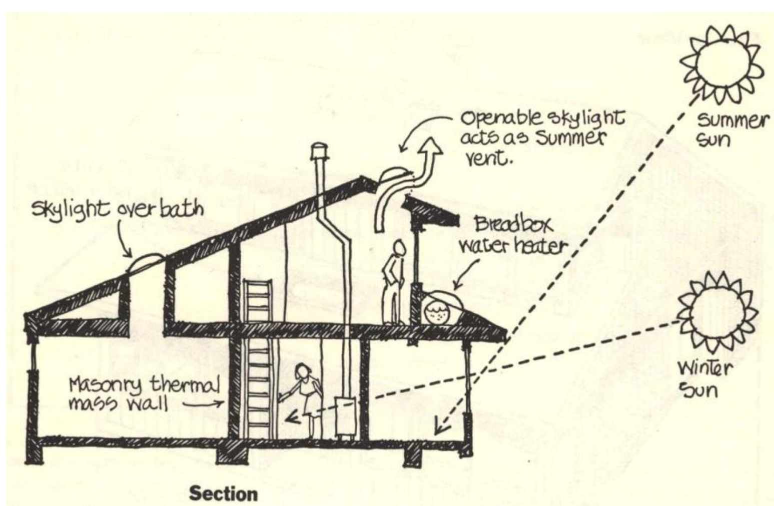


Figure 2.1: Passive solar house
Source: http://www.eslarp.uiuc.edu/arch/ARCH371-F99/groups/k/solar.html

on energy resources, operational costs and indirectly reduces pollution and global warming. Compared to other structures, passive solar houses are known to maintain the thermal comfort for a longer period of the year without the need for mechanical heating or cooling of indoor air. These passive features can also act as an architectural design element for the enhancement of its aesthetics (Hestnes, 1999).

2.3 Hybrid solar house

Hybrid solar houses include a combination of active and passive solar systems for achieving the required thermal comfort. In some cases, a house having a number of various passive solar systems is also considered in this category. Hybrid solar houses can be divided into two groups - firstly, heating and cooling of spaces is satisfied completely by independent functioning of the passive and active solar systems and secondly, passive solar systems are assisted by active system for their functioning or vice versa. These kinds of houses are designed particularly where there are site limitations which prevent the designing of a complete passive solar system (Heinzel and Ledjeff, 2010).

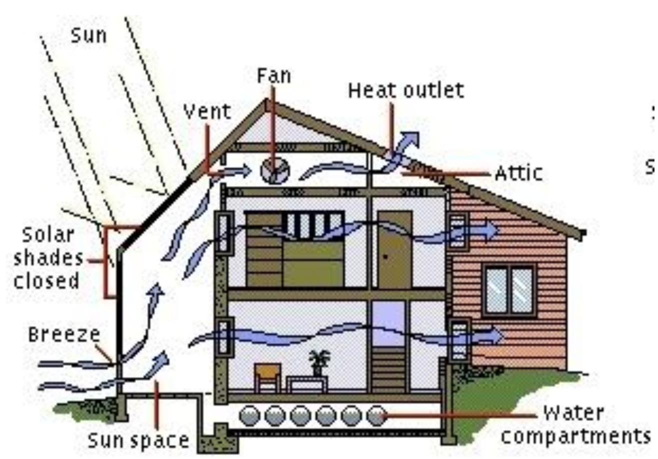


Figure 2.3: Hybrid solar house
Source: http://www.cartage.org.lb/en/themes/Energy/solarenergy/dirct/directcollec.html

All these systems are equally effective and important for creating an energy efficient building. It is the building designer's responsibility to choose from these solar systems depending upon the site location, climate, financial budgets, material and skill of labor availability, aesthetic appeal and also the occupant's lifestyle. Passive solar systems are considered to be more sustainable as they require fewer natural resources for construction and maintenance. The functioning of these systems does not depend on the supply of conventional energy. So a designer should consider a passive system as their first option. But if this system seems to be insufficient, then complementary mechanical heating or cooling devices should also be considered.

3. Climate Analysis

In order to design solar passive elements for houses in Nasik, the main strategy is to understand the climate of Nasik. Thermal comfort can be achieved primarily through the knowledge of climatic data.

3.1 Temperature

In Nasik the high average temperatures range between 26ºC and 37ºC. The highest temperatures are experienced in the months between March and June. Even though there is intense heat during the day, the nights are comparatively cooler during this period, recording average lows between 16ºC to 24ºC. The highest mean monthly temperatures vary from 25ºC to 31ºC, which are recorded in the month of April and May (Nasik meteorological department, 2012). As a result, except for the month of April and May, air conditioning for cooling purposes is rarely used in the houses across Nasik. Figure 3.1 shows the monthly mean maximum, minimum and mean temperatures for Nasik.

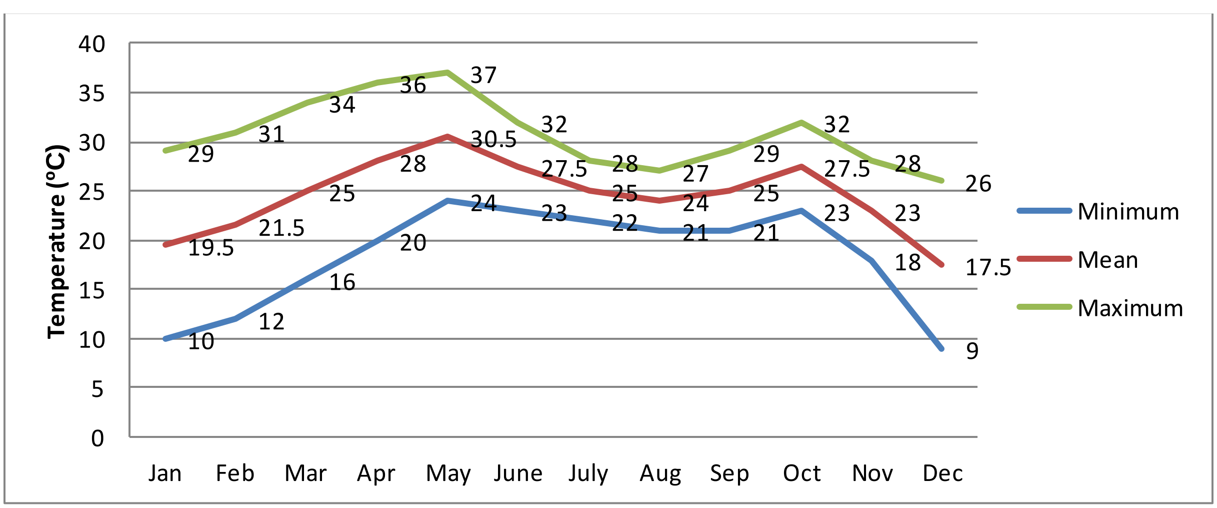


Figure 3.1: Maximum, minimum and mean monthly temperatures of Nasik in the year 2011

3.2 Precipitation

The mean annual rainfall of Nasik (Figure 3.2) varies from the range 600mm to 750mm. The majority of rain is recorded during the months between June to September. There is hardly any rain recorded during the rest of the year. In the past few years, flood like situations were experienced, increasing the average yearly rainfall to 1127.1mm in year 2008 (Nasik meteorological department, 2012).

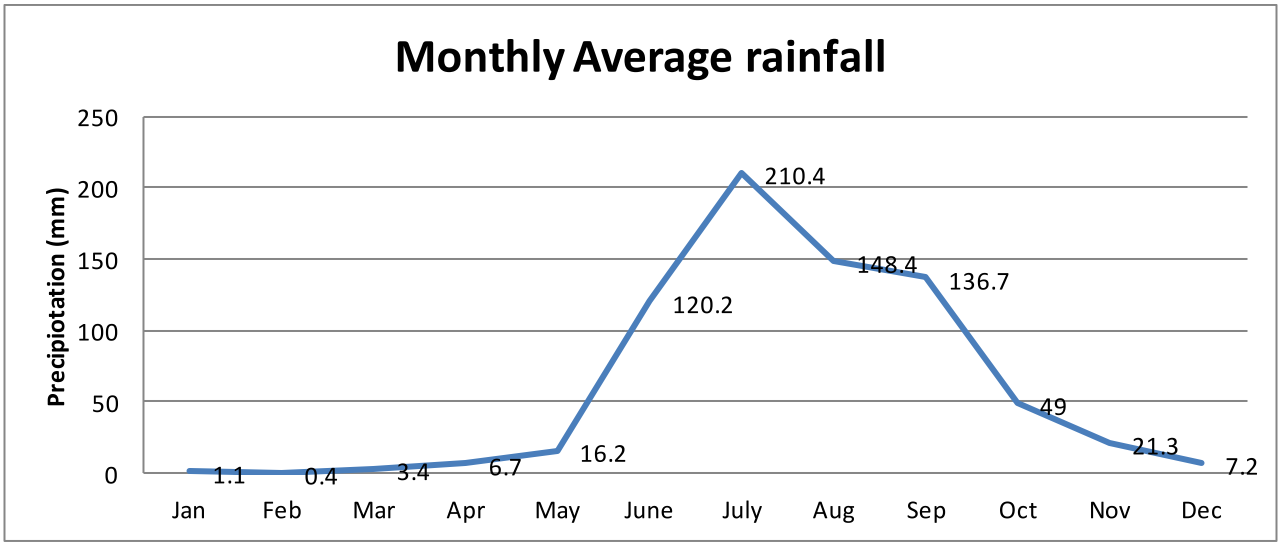


Figure 3.2: Precipitation of Nasik in the year 2011

3.3 Relative humidity

The relative Humidity of Nasik (Figure 3.3) reaches its highest average during the afternoons of the rainy months that is from June to September. It reaches to about 75% during this period. During the rest of the year, the air is comparatively drier with relative humidity ranging anywhere between 25% - 45% in the afternoons (Nasik meteorological department, 2012). It is important to consider relative humidity during the design of solar house, as it causes condensation.

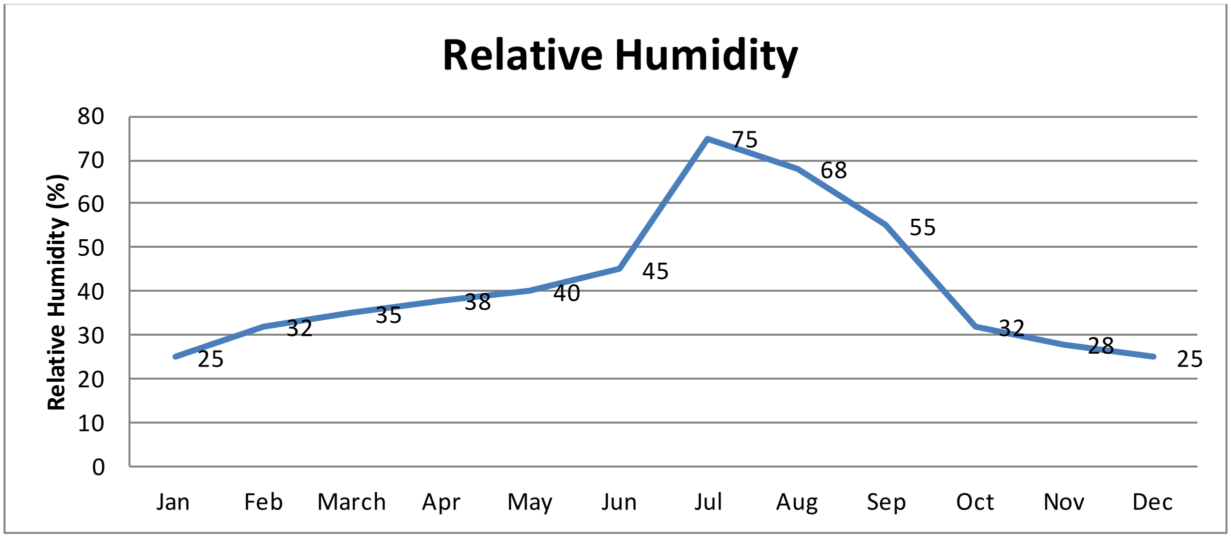


Figure 3.3: Monthly Average Relative Humidity of Nasik in the year 2011

3.4 Wind

Generally, the wind speed experienced in Nasik is light to moderate with some strong winds during the latter part of summer months and monsoon season. During the monsoons, winds flow from south-west in direction. But after monsoon season, winds are light and vary in directions in the early part of the day and flow north-east or easterly in the afternoon. During the winter periods, winds are light and are usually south-westerly and north-westerly in the early period of the day and between north and east in the latter part. During summers, winds blow between south west and north west (Nasik meteorological department, 2012).

3.5 Sun Path

Understanding the Sun path diagram is very important for designing a solar passvie house. Figure 3.4 shows the sunpath for Nasik at latitude 20º02´N and longitude 73º50´E. This chart gives detailed information about the position of the Sun throughout the year. For example, on the 21st of June, it can be observed from the figure that the sun rises from North-East (Azimuth 65º) at 0556 hrs and sets at 1917 hrs in the North-west (Azimuth 290º). On this day, the elevation angle of the sun is approximately 87º at noon. Where as in winters, such as on December 21st, the altitude angle is low at 48º at noon and the sun rises from the South-East (Azimuth 118º) at 0705 hrs and sets in the South-west (Azimuth 245º) at 1801 hrs.

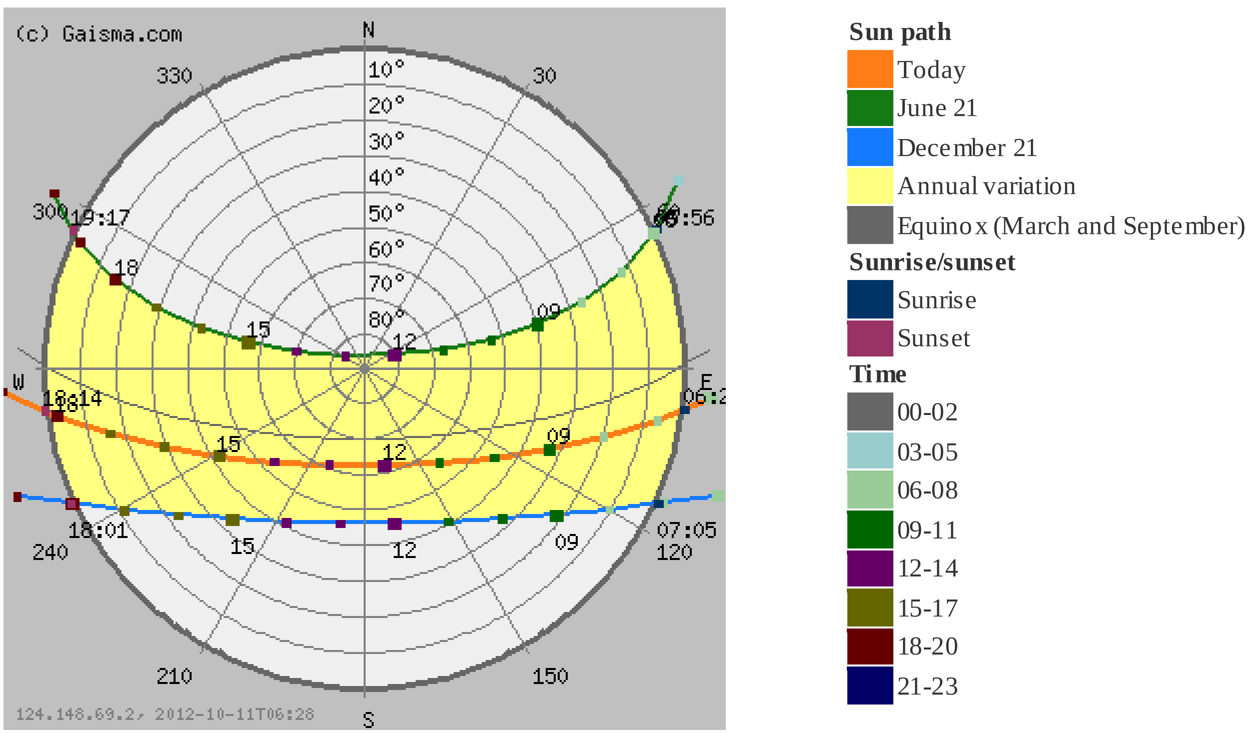


Figure 3.4: Sun path diagram for Nasik
(Image source : http://www.gaisma.com/en/location/nashik.html)

The sun-path diagram provides invaluable data for the direction and availability of solar radiation for heating in winter and for the design of shading devices for the exclusion of solar radiation in summer.

3.6 Radiation

The radiation values (Figure 3.5) are high during summer, that is from Febuary to May with an avearge of 22.95 MJ/m^{2}day. The annual average values of global irradiance vary from 13 MJ/m^{2}day to 25MJ/m^{2}day (Gaisma, 2012).

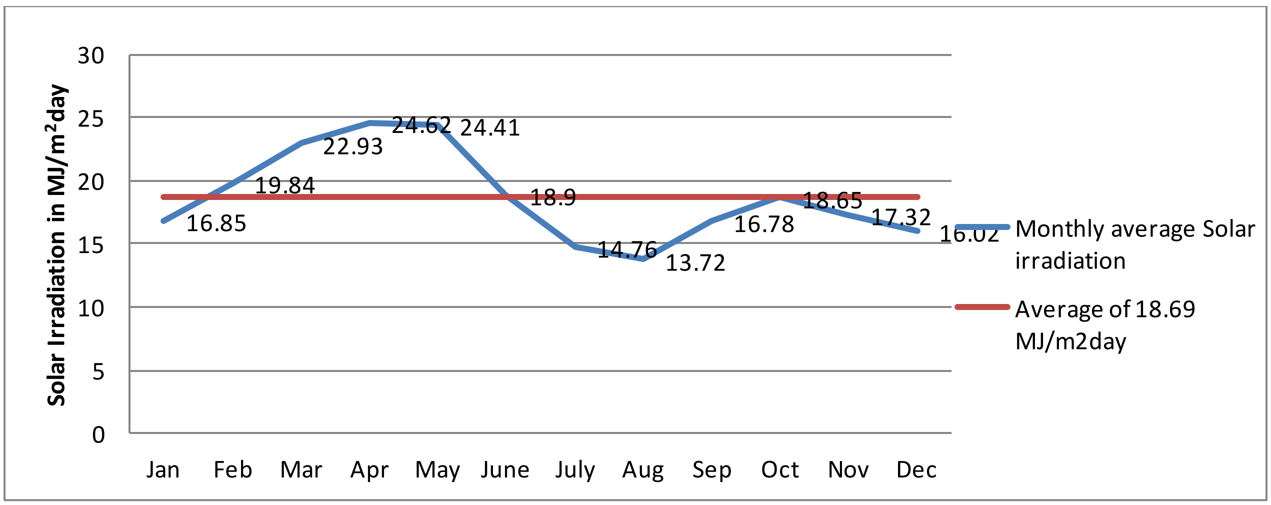


Figure 3.5: Monthly Average Solar Irradiation of Nasik

3.7 Special weather phenomena

During the end of summer season and after the monsoons, Nasik experiences some storms caused due to the depression in the Arabian sea. This brings about widespread rains in and around Nasik. Sometimes, thunder storms are also experienced during these periods (Nasik meteorological department, 2012).

3.8 Seasonal Features

3.8.1 Summer Season (February – May)

Very high temperatures are experienced during this season of the year. The temperatures peak in the month of May. The solar radiation is also on a higher side during this season because of the clear skies. Due to these conditions during the day time, the indoor spaces are the most uncomfortable. Therefore it is very important that the indoor spaces are naturally ventilated by doors and windows. But the nights are comparatively cooler and pleasant. Also the day length is longer during this season, which can be an opportunity to harness solar energy in the form of lighting in houses across Nasik.

3.8.2 Monsoon Season (June – September)

During this season, moderate to heavy rainfall is experienced which is brought in by the South-West winds from Arabian Sea. The days are warm but not too hot and the nights get colder as the season progresses. Sometimes, heavy rains are experienced accompanied with strong winds. Therefore, it is important to shade the windows and other openings appropriately to prevent the rains from entering the house, but not obstructing the natural light.

3.8.3 Winter Season (October – January)

Lowest annual temperatures are recorded during this season. The nights are very cold. The day time is cool and dry with clear skies. There is good opportunity to harness the day heat, store and use during the cold nights (Nasik meteorological department, 2012).

3.9 Thermal comfort

It is important to understand the relation between the thermal environment and the welfare and comfort needs of people. Air temperature is commonly referred as the index for thermal comfort. But there are other factors as well which influence thermal comfort. The physical aspects of any environment are different in all cases and may change from time to time. The physiology of the human body also has an influence on thermal comfort and therefore different people may respond differently to the same kind of conditions. However, the most important thing is to understand, how the thermal environment influences the ability of the human body to maintain an appropriate rate of loss of heat. Hence, thermal comfort can be defined as the physical and psychological condition of thermal neutrality under which the human body does not need to make efforts to reduce or increase heat loss (Szokolay, 2008).

Thermal comfort can be calculated as follows:

$$T_n = 17.6 + (0.31\ T_m)$$

Where, T_n = Thermal neutrality temperature in ºC

T_m = mean dry bulb temperature in ºC

For Nasik, in summer the average temperature is 30.5 ºC (Figure 3.1) in May. Therefore,

$$T_n = 17.6 + (0.31 \times 30.5)$$

$$T_n = 27.05\ ºC$$

In winter, the average temperature for the month of December for Nasik is 17.5 ºC. Therefore,

$T_n = 17.6 + (0.31 \text{ X } 17.5)$

$T_n = 23.02\ ºC$

In these two temperatures, people are expected to feel the most comfortable in the house in Nasik. Further, the comfort zone (Figure 3.6) can be indicated between;

$T_n \pm 2.5K$ for 90% acceptability

$T_n \pm 3.5K$ for 80% acceptability

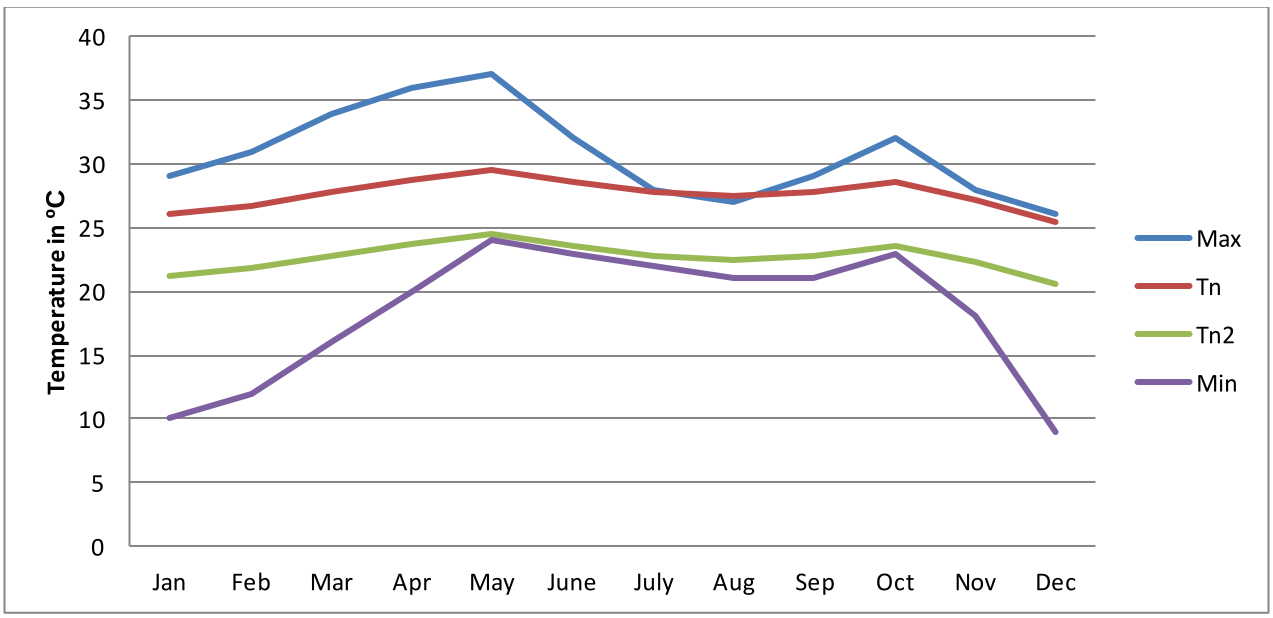


Figure 3.6: Comfort zone and temperatures for Nasik

As seen from the Figure 3.6, thermal comfort in Nasik is experienced in the months of June, July and August. For the rest of the year, the average minimum and maximum temperatures are either below or above comfort zone.

3.10 Summary

From the past climatic analysis, it is clear that the high temperature with an annual average of 30 ºC, low humidity and moderate rainfall are the most particular climatic features of Nasik. Low temperatures are experienced during the months of November to January and high temperatures from February to May, while monsoon season party occurs in the comfort zone.

During summer season, it is important to keep the sunlight entering the house at bay, in order to reduce the amount of solar heat gain. However, natural ventilation is necessary to keep the house cool. Conversely, in winter, the solar heat has to be introduced into the house to keep it warm.

4. Application of Solar Housing principles to Nasik

In this part the key points of solar housing are applied to Nasik according to it's weather conditions and location. It is not a complete guide for solar housing, but a few practical hints and rules of thumb have been designed where possible. This is expected to help the designer to pick some of the suitable elements for designing of a solar house in Nasik. In the book " Solar energy – Fundamentals in Building Design", author Anderson, 1977 has mentioned that elements such as orientation, building shape, site planning, thermal zoning, shading and solar hot water are compulsory for a solar house, where as specific solar heating and cooling systems or a particular construction system may be considered as electives. He also asserted that, a balance must be maintained between orientation, heat collection, heat storage, insulation and sealing, cooling and site planning, when choosing solar housing elements (Anderson, 1977). By going through this material, the designer will get a clear idea of various solar housing possibilities for Nasik.

4.1 Orientation

Buildings with appropriate orientation can provide physical and psychological comfort conditions. The undesirable effects of weather can be excluded to some extent. For example, in cold conditions, the building needs to be orientated such that it can capture maximum solar radiation into the spaces used during daytime for warmth, while blocking the cold winds from entering into the buidling. Whereas, in a hot climate, the solar radiation needs to be kept out of the building in summer, while allowing the cool winds to flow. These features can be achieved by appropriate orientation of buildings. Orientation also plays an important role with respect to wind direction. (Khare, 2011)

Orientation is said to be best when a building as a whole is able to receive maximum solar radiation in winter and minimum in summer. Knowledge about the position of the Sun on a daily basis and seasonal basis is very important for deciding the optimum orientation for a buidling. This can be derived from solar chart (chapter 3, figure 3.4). The knowlegde about the intensity of solar radiation on all external walls of the building and duration of sunshine, is also important for designing a solar house. Once the orientation of the building is finalized, we can control the heat entering into the building by the type of glazing and its area, type of walls and roofs, insulation and shading (Morrissey et. al, 2011).

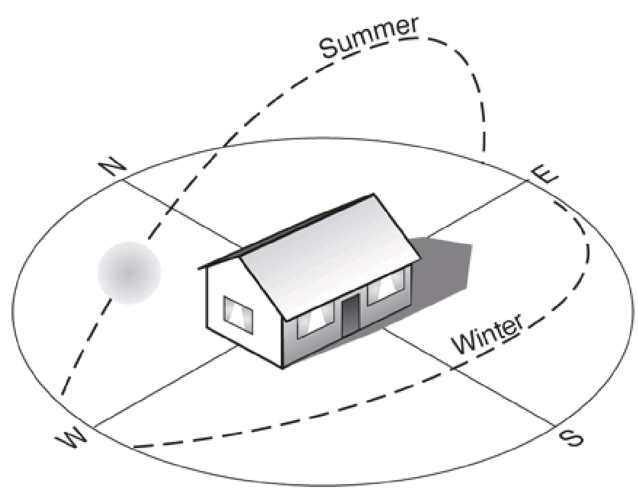


Figure 4.1: Orientation with longer facades on N-S

4.1.1 Orientation for Nasik

In Nasik, the long façades of the building should be orientated towards North-South. During Summer, the East and West sides receive maximum solar radiation. During winter also North-South long facades are preferrable, as South orientation receives maximum intensity of solar radiation. West orientation is crucial as it receives high intensity solar radiation, when internal gains are also at its peak. Therefore, designers need to be careful while designing west façade and spaces behind it. At the building level, orientation affects the heat gain through building enevlope and thus the cooling demand. Orientation may affect the daylight factor depending upon the surrounding build forms, and finally depending upon the windward and leeward direction, fenestration could be designed to integrate natual ventilation (Khare, 2011). The Figures below (4.2, 4.3, 4.4, 4.5) show the solar radiation received on each façade of the building orientation which are modelled in Eco-tect software for New Delhi, capital of India, having similar climate as Nasik (Ecotect analysis 2011, Autodesk).

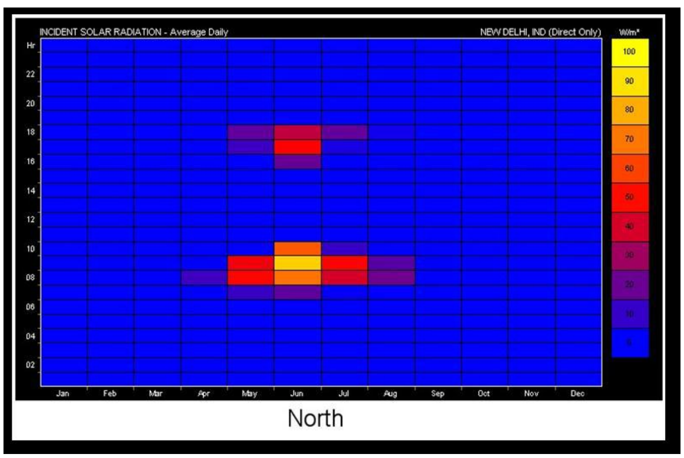


Figure 4.2: Average daily solar radiation received on North orientation in India

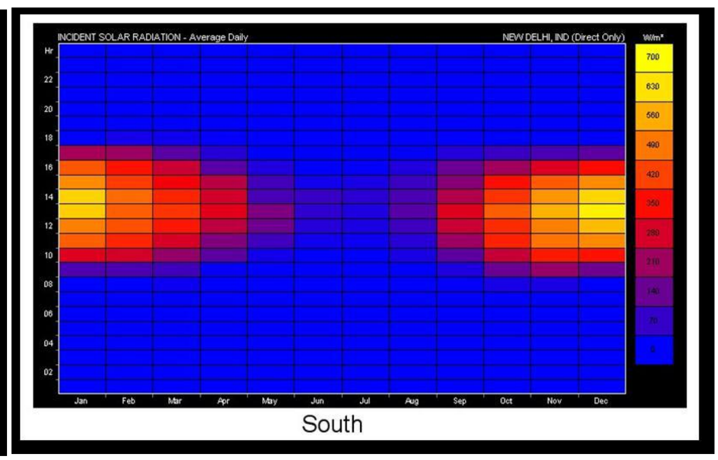


Figure 4.3: Average daily solar radiation received on South orientation in India

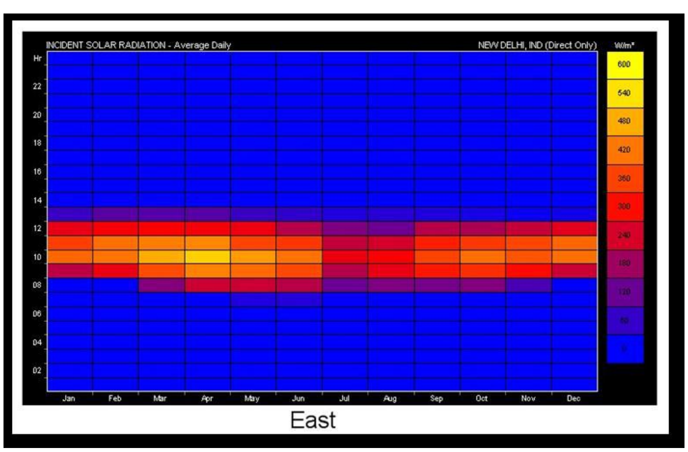


Figure 4.4: Average daily solar radiation received on East orientation in India

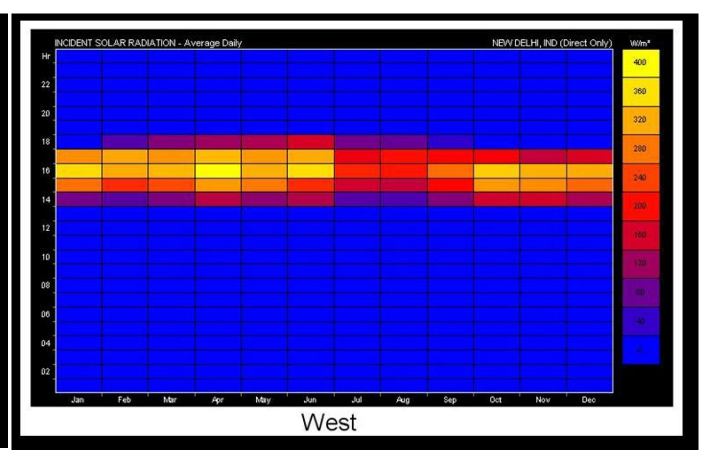


Figure 4.5: Average daily solar radiation received on West orientation in India

4.2 Building Shape

The solar access and wind exposure is affected to some extent by the building form. If also affects the rate of heat loss or heat gain through the envelope of the structure. The thermal performance of the buidling is affected by the volume of space in a building which needs heating or cooling and its relation with the surface area of its envelope. The general design obejctives are to contain the exposure of external elements by means of compact building envelope and careful consideration of the treatment of different elevations and use sheltering and buffering (Capeluto, 2003).

The compactness of the building is measured using the ratio of surface area to volume (S/V). The requirment for artificial lighting depends on the depth of the structure. The need for artificial lighting increases with the increase in depth of the building. The ratio S/V also determines the amount of heat loss or gain from the building. The higher the S/V ratios, the higher will be the heat loss or gain from the structure. The circular geometry has the lowest S/V ratio. Thus the conduction gains from windows are least in circular geometry in comparison to other building geometries which is most energy efficient in temperate climate (Dekay, 2001). But its difficult to plan a space efficient, circular shaped building on a rectangular shaped plot.

4.2.1 Building shape for Nasik

The shape with a minimum S/V value, suitable with the plot size and shape, is preferable for the climate of Nasik. The building form also determines the air flow pattern around the building directly affecting its ventilation. Obstructed wind can result in creating different air pressure - a positive pressure in the windward side and a negative pressure in the leeward side. This helps in establishing a new airflow path around the structure. Therefore the wind patterns around and across the building can be determined and modified with the help of the shape of building (Dekay, 2001).

4.3 Site planning

Certain characteristics of the selected site can affect the overall thermal performance of a solar house. It is advisable that the designer of the solar house should take advantage of the favorable site conditions while minimizing the effects of critical ones. We need to consider three important factors for site planning, which are the micro-climate of the place, the immediate aurroundings of the site and the extent to which favourable changes can be made to the existing site conditions.

Important information regarding the weather that is, wind data, amount of sun shine and temperature data are very essential at this stage of planning. The direction of wind and speed needs to be noted, as the summer breezes help in cooling the building whereas, winter breezes increase building heat loss. The solar radiation data is very important especially for the summer season. Water bodies like the oceans, rivers, lakes, ponds contribute in modifying the micro-climate. They can provide a source of thermal mass. Water bodies also reflect solar radiation, which can be advantageous in winter by directing the solar radiations towards building (Szokolay and Sale, 1979).

The immediate physical surroundings of the site may contribute in the thermal performance of the structure. The nearby hills can affect the hours of sunshine and sunset, which can further affect the length of the day (Szokolay and Sale, 1979). In India, if there are hills on the west of the site, then they can be advantageous during summer. But hills on the south or south-east can block the available solar radiations in winter. Hills also contribute in protecting the house from cold winter winds and also in channelizing the cold winter winds or cooling summer breezes towards the building.

The vegetation around the site of the solar building can influence the thermal performance to a great extent. Vegetation can protect the building from winter winds and channelize the desirable summer breezes. However, if the trees are also not positioned correctly, then the opposite may also be true. Tall trees can provide shade in summer but can also cause overshadowing in winter. The same can happen with adjacent buildings, that either shade in summer, overshadow in winter or channel summer and winter winds. Therefore, it is essential for the solar house designer to consider the future possibilities of site conditions and the extent of any future building development (Jansson, 2008).

All sites are different, having various characteristics, some positive which are perfect for solar housing and some negative creating almost every undesired effect. But a designer needs to establish a balance between all the fixed and changing natural and man-made forces to make these forces work for the solar house as far as possible rather than against it.

4.4 Thermal Zoning

Energy efficiency and greater thermal comfort can be gained by dividng a solar house into separate zones. Different spaces have different thermal comfort requirements. So, it is not necessary to have a uniform temperaure throughout a solar house.

Based on the thermal comfort conditions, the arrangement of spaces can provide optimum thermal zones. The designer needs to identify the spaces which need warmer temperatures in winter and locate them in a way to receive the sun either directly or indirectly. It is also essential to locate the spaces which need to be in coolest part during summer. A balance should be maintained between the summer and winter requirements (Willrath. H, 1992).

4.4.1 Thermal zoning for Nasik

The temperature level in each room depends on its solar radiation exposure. Nasik lying in the Southern Hemisphere, the south side will be the warmest all year since the sun is in the southern sky. It is expected that the west having maximum exposure in summer will be hot and in winter it will be cold. The north-side will be the coolest throughout the year. For Nasik, the west side being the hottest side, toilets, washing areas, staircase block and other services are preferred to be located in this side. South side being warmest side, it is beneficial for the location of kitchen and dinning. Living area and other day activity areas, which are used during the daytime are preferred to be located in the North or North-east side, as it is the coolest side all year round. Bedrooms are used only during the nights, and can be located in the south or south-west side, as it can capture the warmth for winter cold nights and avoid the early summer heat.

4.5 Shading

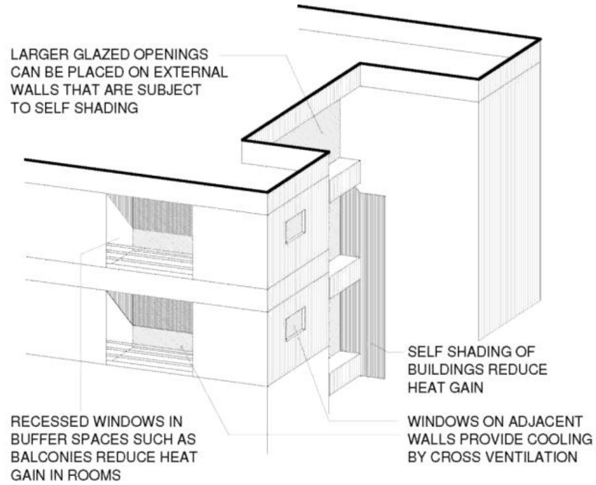


Figure 4.6: Building elements used to reduce heat gain

All the elements of a building are vulnerable to heat gains. Proper shading is therefore a very important aspect in solar passive building design. Self-Shading can help shade the external facades with their building profiles like H-type profile or L-type profile. Shading devices like chajjas – horizontal fin on the top on the window, acts as a barrier and blocks the incident solar radiations on the external facades of a building, thereby resulting in reduction in the heat gain of buidling as a whole. It has been observed in India, that a maximum room temperature in low-rise residential structures can be reduced by 4.6ºC by shading a window with a help of a simple horizontal fin of 750mm in depth (Bandyopadhyay, 2001). Thus the thermal performance of a building can be improved by using shading devices for the external facades exposed to solar radiations.

External shading is the most effective way of shading, as it cuts off direct sulight during summer and allow winter sunlight to enter inside the space. However, in cloudy weather or if not deisgned properly, these can reduce daylight availability inside the space. For such cases, external moving shading devices are preferred. External shading devices should be designed according to the orientation of façade. For instance in Nasik, north orientation requires minimum or no shading. On south orientation external shades should be designed on basis of the sun path diagram. Shading devices on south orientation could be permanent in nature, as most part of the day Sun remains

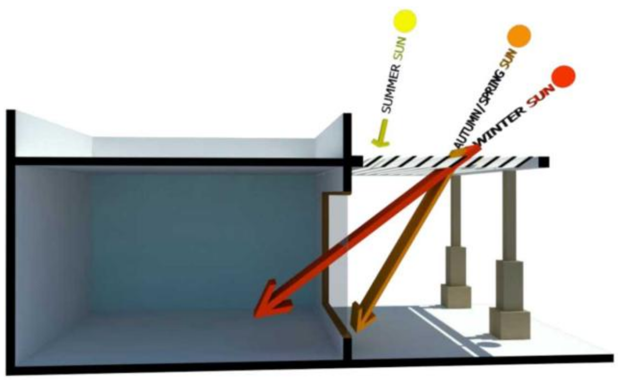


Figure 4.7: Effective external shading for openings

Figure 4.8: Horizontal and vertical fins as external shading for openings

in south orientation. It is preferable to design movable external devices on east and west facades, so that the shades could be removed after Sun faces opposite orientation (Chiras, 2002).

4.5.1 Shading for Nasik

For the temperate climate of Nasik, the taller structures should be positioned in the south-side, which helps in shading other structures in a cluster. External facades likes walls and other fenestration can be shaded with the help of some projections like chajjas, balconies, movable fins and landscape. Internally, the openings can be shaded with some vertical covers like curtains or blinds. To further reduce the solar heat gains through glazing, tinted glass, reflective glass or high U-value glass can be used. Shade factor is used to measure the effectiveness of these shading devices. It is defind as ratio of solar heat gain from the opening, to the solar heat gain through a 3mm plain glass through the same opening (Bandyopadhyay, 2001).

4.6 Landscape

Landscaping is one of the most important factors affecting the micro-climate of a place. Appropriate desiging of landscape can reduce the intensity of direct sun radiations striking the external façade and prevent it from heating the building. It is the best way to provide a buffer from heat, sun radiation, noise and airflow or for altering airflow path in a solar passive design house. It prevents the reflected light by the ground or other surfaces, from stricking the building façade. Additionally, the shade created by trees reduce air temperature of the micro-climate around a building through evapo-transpiration. Appropriately designed roof top gardens can contribute in reducing the heat load of a building (Wines and Jodidio, 2000).

Figure 4.9: location of trees to protect from winds
(Source: www.thedailygreen.com)

4.6.1 Landscape for Nasik

Locating deciduous trees on the south side of the site is beneficial in a temperate climate. During summer season, deciduous trees cut off direct sun radiation, while in winter season, these trees shed their leaves allowing the direct Sun radiation to heat up the building.

Planting dense trees or shrubs on the west and northwest side of the site will help in blocking the evening sun-set radiations in summer. Solar houses can be naturally cooled by planting trees or shrubs to divert and channelize the south-easterly summer winds into the house. Trees, which serve as a wind breaker or form shelterbelts, diminish wind. Different types of shades around the site can be created by combining various landscape elements, like climbers or vines on trellies or pergolas. Certain climbers are also useful for shading exposed walls from direct sunlight. Trees also provide visual relief and a psychological barrier from traffic and thus reduce pollution on site (Nayak, Hazra and Prajapati, 1999).

4.7 Colour and Texture

The colour and texture of the external surface affects the quantity of heat absorbed or reflected by it. The external surface with a smooth and light coloured finish will result in reflecting more heat and light than compared to a rough textured surface finish. A rough textured finish leads to self-shading, thereby increasing the area for re-radiation. Whiter or lighter shades of surfaces reflect higher amount of solar radiations. Therefore, they are used in temperate climates to reduce the heat gain of building. Solar glare can be reduced by using heavy texture with light pastel colours on external surfaces. For cold climate, dark colours are used on surfaces as they absorb higher amount of solar radiation, thus heating up the building (Probust and Roecker, 2011).

5. Concepts for Solar Passive Design as Design element for Nasik

As a practicing architecture from Nasik, the biggest task to start planning a solar house is to convince the clients for integration of solar passive concepts in the design. In this modern world of architecture, people want their house/building to be one of the best aesthetically designed structure, for which they are ready to compromise on energy efficiency of the building. But they need to be convinced that, a master piece can be created with well-designed solar passive concepts without sacrificing energy efficiency. It can be made as attractive as a conventionally designed building and still save energy and money.

In this chapter, I have tried to develop some solar passive concepts for houses in Nasik, which will help in the aesthetic enhancement of the structures. A few detailed drawing and photos are used to demonstrate the successful application of these designs. These concepts can be used a block designs to plan a solar passive house with appropriate integration.

5.1 Central Skylight

A central courtyard has always been an element of traditional Indian architecture as a source of natural light and ventilation. But due to security reasons because of its openness, the implementation of these courtyards in residential designs in India is reduced. Now-a-days, there are many solutions available to

Figure 5.1: Traditional Indian central courtyard
(Source: www.homindeo.com/tag/skylight-room/)

overcome problems of security. One of the best ways to design a central courtyard is by providing a cover on the top without affecting its performance, known as central skylights.

Figure 5.2: Skylight effect in the house
(Source: www.mathtourist.blogspot.com.au/10/dome-sky-light.html)

The Famous architect Frank Llyod Wright was known to light up his interior spaces with natural light and often said, “The best way to light a home is nature’s way”. Natural light creates a better living environment. It is known to make spaces visually interesting and also reduce energy consumption in electricity. And one of the easiest ways to open up to natural light and improve the interior ambience is by setting up skylights. A sense of spaciousness is created by the streams of natural light and also filling the space with cheerful disposition. A clear glass skylight provides a beautiful view to the twinkling or moonlit skies. Architect Murthy from Bangalore, India mentioned, “The experience below a skylight will be very pleasant because the direct heat and sunlight are cut to more than 60%.” The play of light and shade created by the skylight can add dramatic effect in the space (Edwards et. al, 2006).

Figure 5.2: Circular Skylight
(Source: personal photos)

The skylights, designed with vertical steel mesh on the base, can be used for natural ventilation. The stack effect created by the skylight can be used for natural ventilation in solar houses in Nasik. The air gets heavier at low temperature than the air at high temperature. Therefore the warm air from the bottom of the house rises up and escapes through the skylight's vent, making room for the cool air. This helps in maintaining thermal comfort in the house as well as flow of natural air. While designing the skylight, care must be taken to provide sufficient overhang to protect the rain from entering the house. These types of skylights can be designed in any preferable shape like round, square, pyramid etc. and in any size. They can also be covered with different types of glazing or translucent acrylic sheets available from the market. Now-a-days, new U-V protective glazing is also available which further lowers the heat gain.

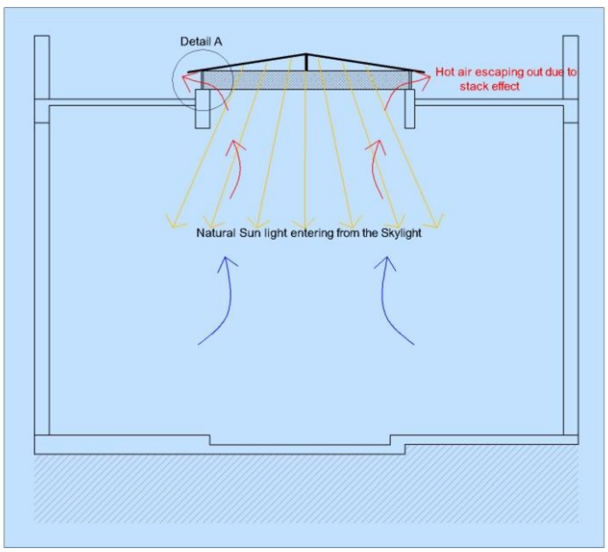


Figure 5.3: Skylight effects in detail

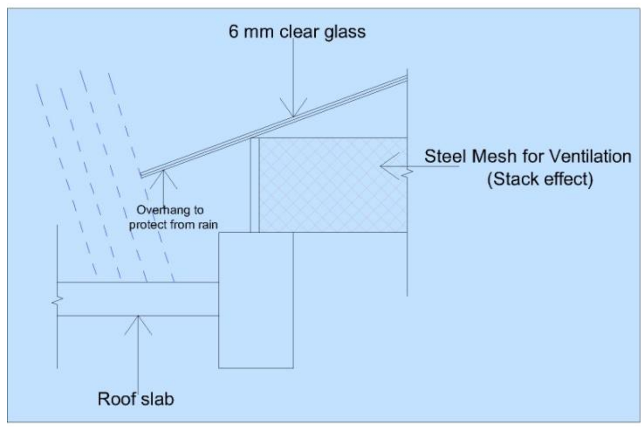


Figure 5.4: Skylight detail - A

Figure 5.5: Skylight in a house
(Source: personal photos)

Figure 5.6: Steel mesh for Natural ventilation in the Skylight
(Source: personal photos)

5.2 Shading Device – Boxed Window

In the last chapter 4.5, the importance of shading is discussed in detail. It is important to provide appropriate shading for the house in summer while allowing the winter sun radiation in the house to maintain thermal comfort. It is beneficial to shade the whole building, but shading of windows is crucial. A window must be shaded from solar radiation and also from the diffuse and reflected solar components to prevent passive solar heating during summer season. The thermal comfort level inside an enclosed space can be affected to a great extent by the decisions on placement of shading devices. Other than providing natural light, windows are also needed for natural ventilation in the house.

Considering all the above requirements, a boxed window can be integrated in the solar house design in Nasik. Boxed windows provide appropriate shading, as well as create attractive volumetric elevations for the house. The box profile of this window, not only block the day time solar radiation, but also the summer setting sun radiations. A flower bed can also be designed in the boxed windows, to connect the inside space with nature and further enhance aesthetics of the house. Graphic details of integration of the boxed windows in planning of solar house are given below.

Figure 5.7: Application of Boxed Window
(Source: Self designed)

Figure 5.8: Application of Boxed Window
(Source: Self designed)

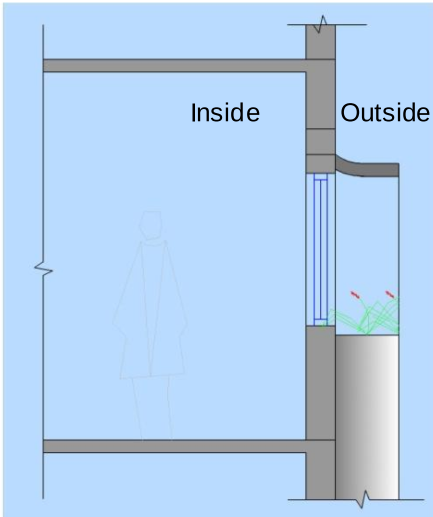


Figure 5.9: Detailed section of a Boxed Window

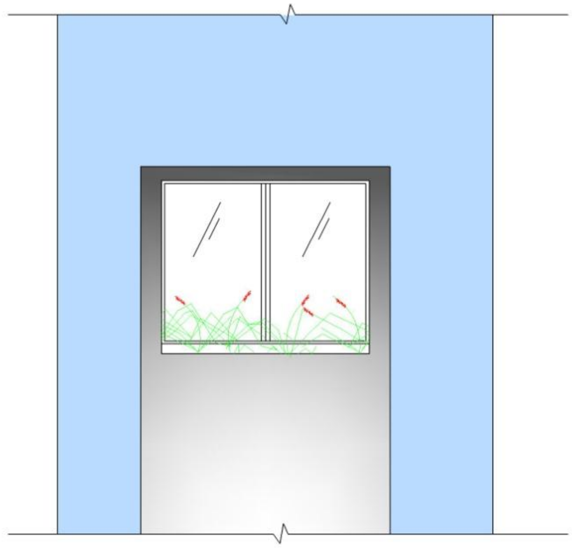


Figure 5.10: Detailed elevation of a Boxed Window

Figure 5.12: View Boxed Window

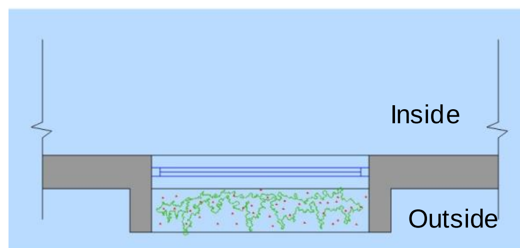


Figure 5.11: Detailed Plan of a Boxed Window

5.3 Solar Pergolas

Pergolas are commonly used as a landscape element to design beautiful gardens. But pergolas, when designed appropriately can be used also as semi-shading devices for external spaces like terraces, balconies and

Figure 5.12: Pergolas used for external shade
Image Source: Personally photograhed

porches. Interesting play of light and shade is created by these pergolas, giving a dynamic feel to the space. Planting some climbers or creepers with the pergolas, enhances the aesthetic look as well as merge the structure with nature. They can be designed in various materials like wood, aluminum, steel, concrete etc. according to the requirements (Banbrook et.al, 2011).

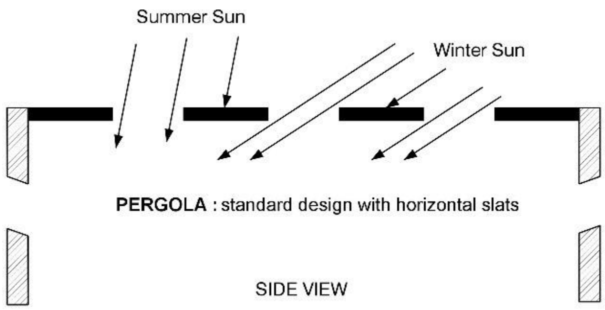


Figure 5.13: Standard Pergola design detail

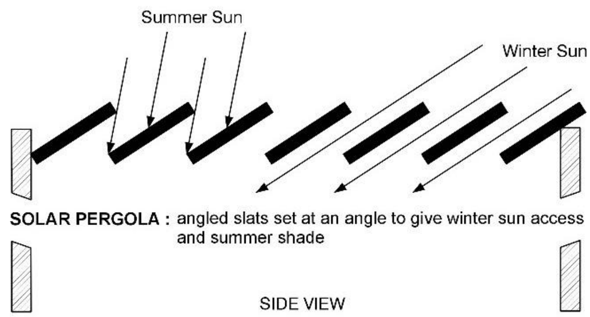


Figure 5.14: Solar Pergola design detail

Standard pergolas allow sunlight in all seasons and can contribute to solar passive heating when needed. Solar pergolas are designed with angled fins to cut out the summer sun and let in the winter sun for warmth. This helps to completely shade the space in summer and prevent the space from passive heating.

Figure 5.15: Steel Solar Pergola used for shading the terrace

Figure 5.16: Wooden Solar Pergola used for shading the terrace

5.4 Brick Jali wall – perforated brick wall

Clay brick is one of the most commonly used building materials in India. Using clay brick has many advantages. Exposed brick construction adds to the aesthetic appeal of the structure by its vibrant color. It is a good thermal and acoustic insulator. Compared to other materials, it has zero maintenance cost. It can be used for construction for residential, commercial or any type and shape of structure due to its flexibility in application and its resistance to fire (Gupta, 2000).

Brick jali wall is a very effective element for solar passive design. This wall is a perforated brick screen which utilizes natural air movement to cool the interior space and create intricate patterns of light and shadow. Structures built with these walls are thermally comfortable even on the most oven-like day. The gaps between the bricks allow natural air and daylight through the wall, while defusing the glare of direct sunlight. Brick jali walls are easy to erect and comparatively cheaper as well. One can play and create interesting brick patterns for the Jali (Hochschild, 2000).

Figure 5.17: Application of Brick jail wall
Image Source: Personally photographed

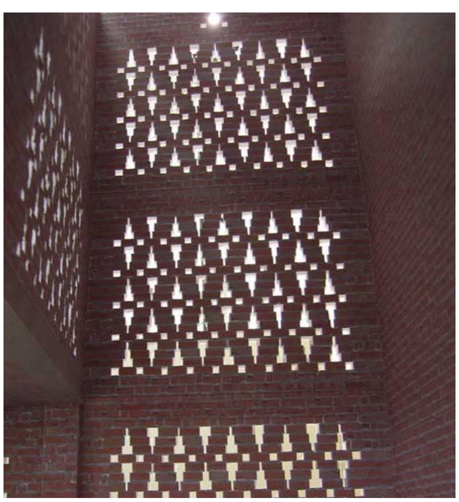


Figure 5.18: Interior effect of Brick jail wall
Image Source: Personally photographed

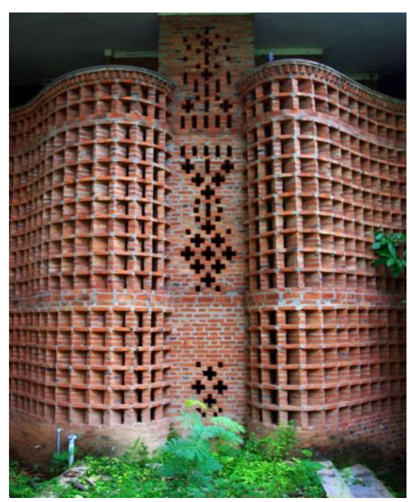


Figure 5.19: Unique design of Brick jail wall
Image Source: Personally photographed

Clay bricks are easily available in Nasik. They are sundried and kiln baked bricks of a vibrant red color. Construction of the brick jali wall on the south side can help to block the intense south-side solar radiation, while allowing natural light and air into the enclosed space. These walls can protect the interiors from rains up to some extent, but not completely. This is the only disadvantage of these walls, especially when the rains are pouring down in a very slanting angle accompanied with harsh winds.

5.5 Recessed Balcony

Balconies form an important part of a private open space for a house. Especially in Indian house, it is a very essential element due to its very various uses like, for drying clothes, grains, solar cooking, etc. In a multi-storey structure, they are the only source of private open space and to enjoy direct solar benefits.

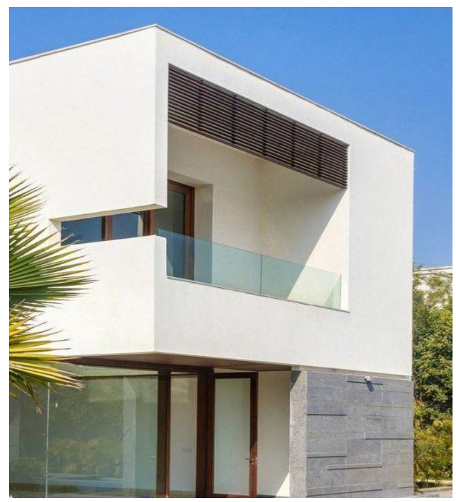


Figure 5.20: Recessed Balcony
Image Source: Personally photographed

A recessed balcony is formed by a set in the external façade. It not only creates and extends the building interior to the outside but also shades the openings from direct southern sunlight. A recessed balcony act as open spaces and transitional spaces for the upper floors of the building and enhance the wind flow into internal spaces. It adds to the elevation of the structure by

Figure 5.21: Recessed Balcony
Image Source: Personally photographed

creating interesting volumetric compositions giving a depth to the building facade. These types of balconies can be directly connected to the natural greenery by planting a flowerbed at the edge (Jain, 2009).

Figure 5.22: Combination of Boxed windows, Solar Pergolas and recessed Balcony for a Multi-storey building

Figure 5.23: Combination of Boxed windows, Solar Pergolas and recessed Balcony for a Free standing single house

5.6 Roof Garden

Nature is said to be a human beings best friend. It has the power to provide comfort and peace. Integration of nature with today's concrete structures is very necessary to provide comfort and visual pleasure to its occupants. In developing countries like India, where there are space constraints, one cannot afford to have a garden around his house.

Shading of the roof is very important to reduce the heat gain of the building. Shading devices made of concrete, galvanized iron sheets, etc. can

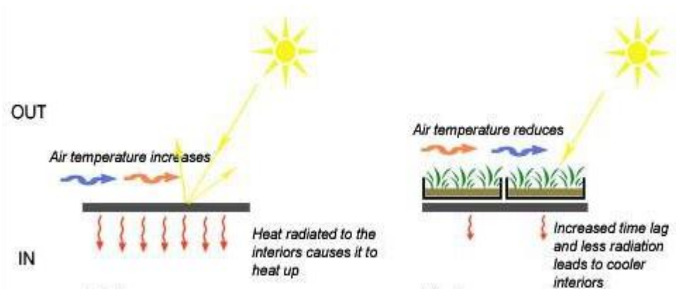


Figure 5.24: Reduced heat gain by Roof Garden

provide efficient shade during daytime, but during the night time it does not allow the heat to escape in the atmosphere (Wines and Jodidio, 2000).

Figure 5.25: Roof Garden in Nasik
Image Source: Personally Photographed

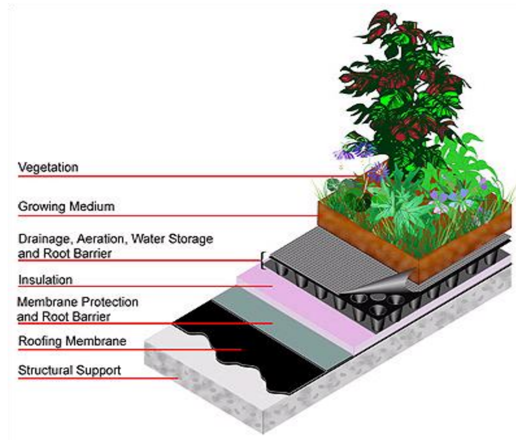


Figure 5.26: Roof Garden structural details
Image Source: http://www.lidstormwater.net/greenroofs_home.htm

For all the above requirements, designing roof gardens with some deciduous plants and creepers is an appropriate solution. The roof temperature is reduced by evaporation from leaf surfaces. During the night time, the roof surface temperature is even lowers than the air temperature. It also helps to keep the inside of the building cool by its insulating properties (Baskaran, 2010).

6. Tecto Hand Calculations

In this chapter, the effectiveness of the solar passive elements designed into a residential house in Nasik which were discussed in the previous chapter are tested for their effectiveness through Tecto hand calculations.

Structure : Ground floor + 1, Free standing and facing North side.

Material Details:

Roof: 150mm concrete slab + 100mm brick coba + roof tile finish

"U" value = 2.43 W/m^2K

Walls: 230mm brick wall, plastered on both sides

"U" value = 1.98 W/m^2K

Glass: 6mm single clear glass

"U" value = 5.7 W/m^2K

SHGC = 0.85

Light transmittance = 89%

Day lengths:

Summer = Day 14hrs, night 10 hrs

Winter = Day 10hrs, night 14hrs

<u>Temperatures:</u>

From fig.3.6 - Thermal Comfort, the months from June to September lie almost in the comfort zone. So only the winter and summer season are considered for calculations.

From Chapter 3,

Summer Temperature (Feb-May): Average Maximum = 35ºC ,Average Minimum = 24ºC

Winter Temperature (Oct-Dec) : Average Maximum = 26ºC ,Average Minimum = 9ºC

The sky is clear, in seasons, summer and winter, so the cloud factor is not considered for the solar heat gain.

<u>Comfort temperatures to be achieved:</u>

Summer = 27ºC (From Chapter 3.6)

Winter = 23ºC (From Chapter 3.6)

<u>Area statement:</u>

Total Floor area = 120 sq.m.

Total roof area = 60 sq.m.

Total Volume = 288 cu. m.

<u>Total Glazing Area</u>: North side = 4.14 sq.m.

South side = 5.52 sq.m.

East side = 6.4 sq.m.

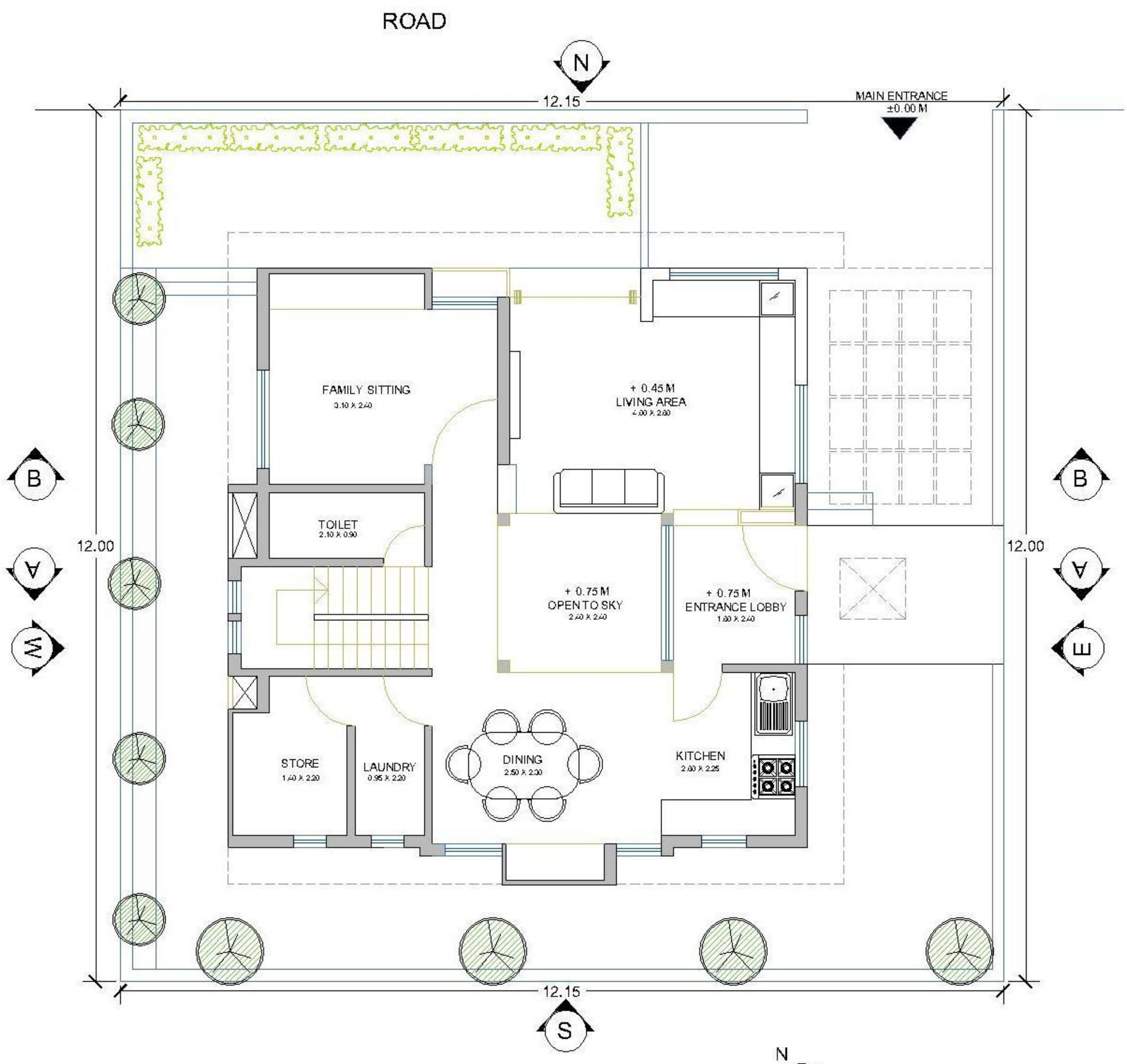
West side = 4.64sq.m.

Skylight = 5.76 sq.m.

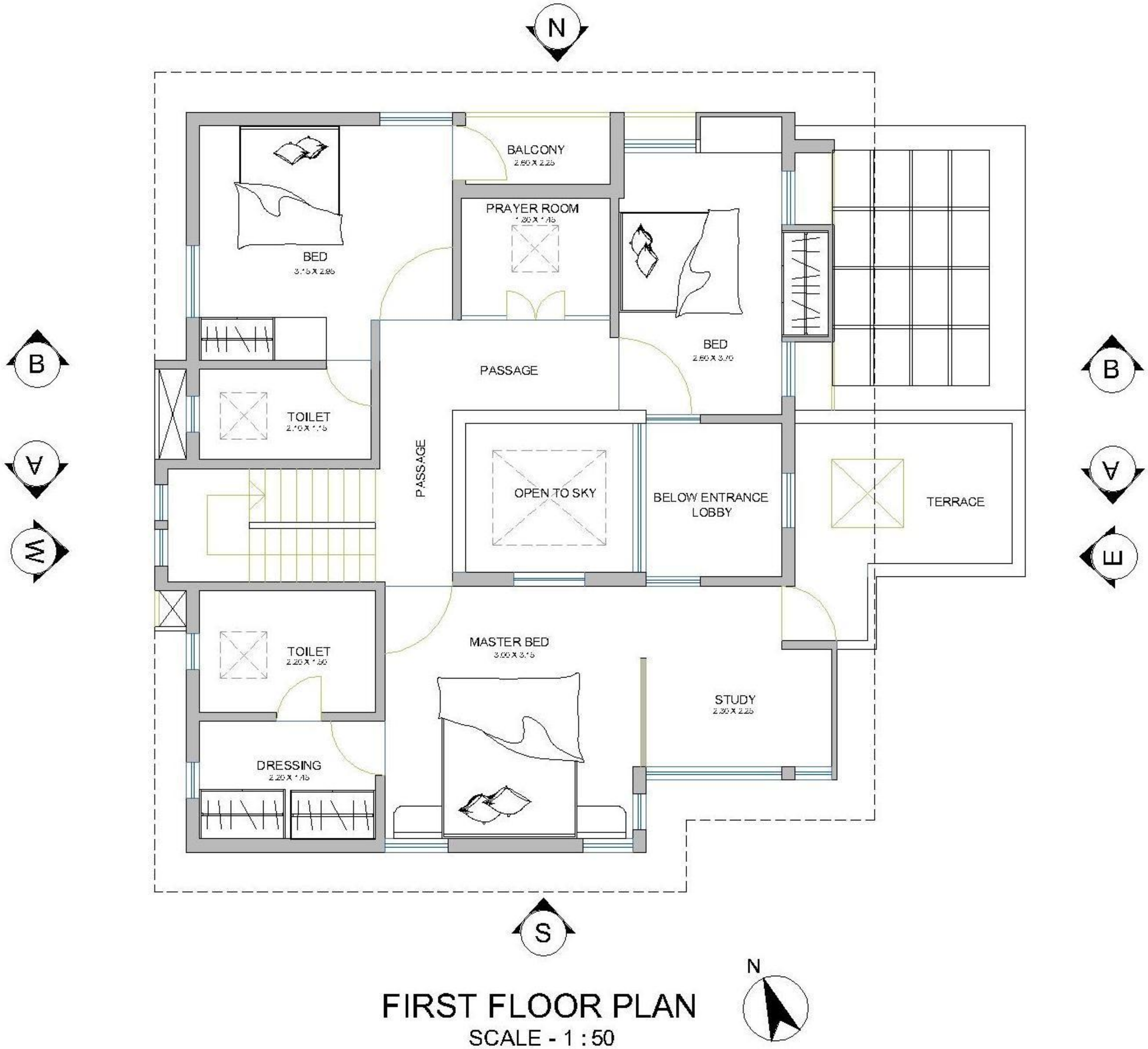
<u>Total Wall Area</u>	: North side = 31.86 sq.m.	East side = 32 sq.m.
	South side = 30.48 sq.m.	West side = 33.76sq.m.

Formulas used in the calculation are used from - The Art of the Science - Climate sensible design, Lecture2 – Session3, framed by Garry F. Baverstock.

Detail Drawings:



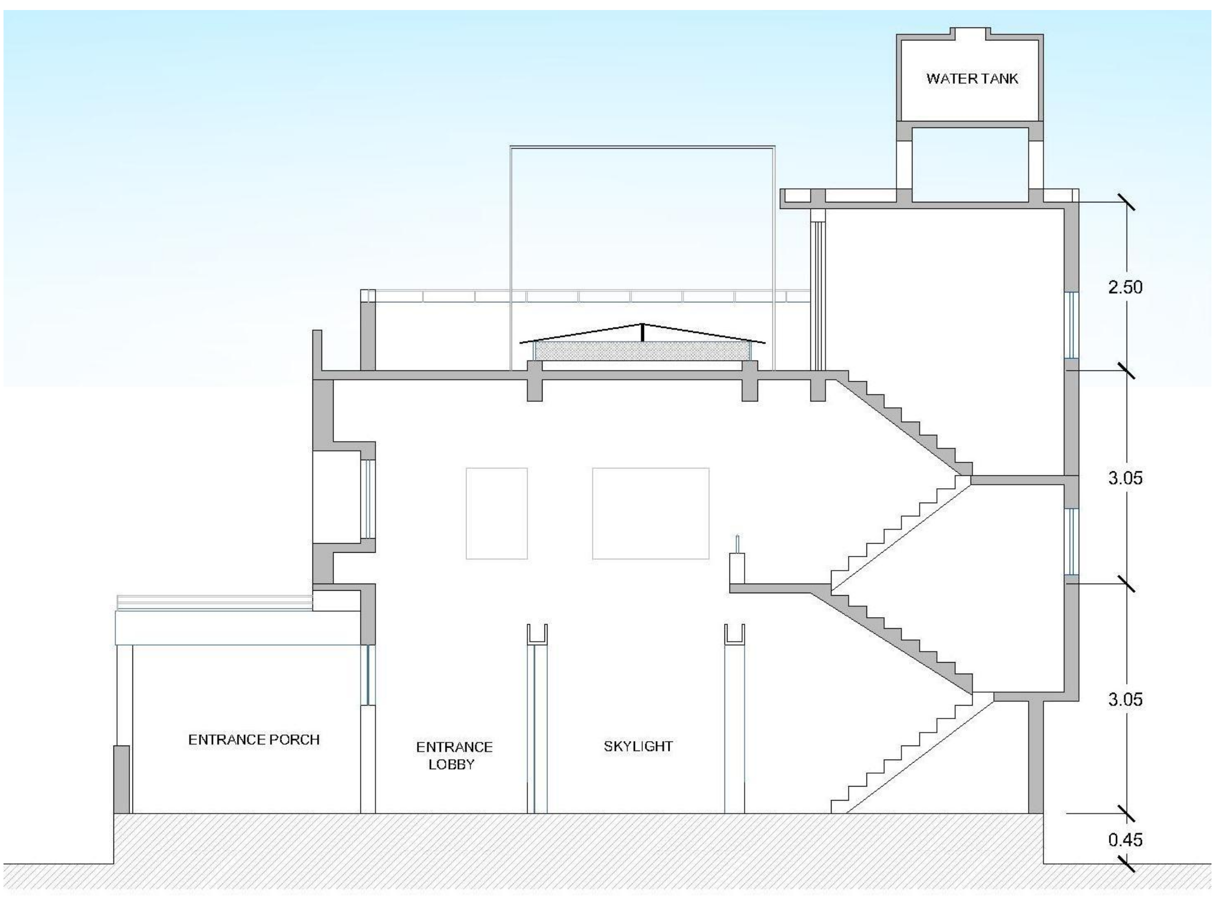
GROUND FLOOR PLAN
SCALE - 1 : 50



FIRST FLOOR PLAN
SCALE - 1 : 50

SECTION BB

SCALE - 1 : 50



SECTION AA

SCALE - 1 : 50

Winter Calculations:

- <u>Solar glazing gains</u>:

Formula : Radiation = S X I X A

S = % exposure factor penetrating the window

(The exposure figures take into account SHGC = 0.85)

I = Total diffusion and direct radiation

A = Area exposed

(Glazing areas include the skylight area)

North = 0.8 X (4.52 ÷ 3.6) X 5.58 = 05.60 KWH/day

South = 0.8 X (15.20 ÷ 3.6) X 6.96 = 23.50 KWH/day

East = 0.8 X (10.63 ÷ 3.6) X 7.84 = 18.51 KHW/day

West = 0.8 X (10.63 ÷ 3.6) X 6.08 = 14.36 KWH/day

<u>Total Glazing gains = 61.97 KWH/day</u>

- Transmission heat loss through roof:

Formula: $Q_c = U \times A \times (t_o - t_i) \times hrs \div 1000$

For Daytime, $U = 2.43\ W/m^2K$

$A = 60$ sq.m.

$t_o = 29^o\ C$

$t_i = 23^o\ C$

$Q_{c1.1} = 2.43 \times 60 \times (29-23) \times 10 \div 1000$

= 8.748 KWH/day

For Night time, $U = 2.43\ W/m^2K$

$A = 60$ sq.m.

$t_o = 15^o$ C

$t_i = 23^o$ C

$Q_{c1.2} = 2.43 \times 60 \times (15-23) \times 14 \div 1000$

$= -16.33$ KWH/day

Therefore, <u>Total Transmission heat loss through roof $Q_{c1} = -7.58$ KWH/day</u>

- <u>Transmission heat loss through walls</u>:

For daytime,

North side = 1.98 X 31.86 X 6 X 10 ÷ 1000 = 3.78 KWH/day

South side = 1.98 X 30.48 X 6 X 10 ÷ 1000 = 3.62 KWH/day

East side = 1.98 X 32 X 6 X 10 ÷ 1000 = 3.80 KWH/day

West side = 1.98 X 33.76 X 6 X 10 ÷ 1000 = 4.01 KWH/day

Therefore, for daytime total heat loss $Q_{c2.1}$ = 15.21 KWH/day

For night time,

North side = 1.98 X 31.86 X (-8) X 14 ÷ 1000 = -7.06 KWH/day

South side = 1.98 X 30.48 X (-8) X 14 ÷ 1000 = -6.76 KWH/day

East side = 1.98 X 32 X (-8) X 14 ÷ 1000 = -7.09 KWH/day

West side = 1.98 X 33.76 X (-8) X 14 ÷ 1000 = -7.48 KWH/day

Therefore, for night time total heat loss $Q_{c2.2}$ = -28.39 KWH/day

Therefore, <u>total transmission heat loss through walls Q_{c2} = -13.18KWH/day</u>

- Transmission heat loss through windows:

The window U value for daytime = 5.70 W/m^2K

Night time = 2.00 W/m^2K (impact of closed curtains, etc)

For daytime,

North side = 5.7 X 5.58 X 6 X 10 ÷ 1000 = 1.90 KWH/day

South side = 5.7 X 6.96 X 6 X 10 ÷ 1000 = 2.38 KWH/day

East side = 5.7 X 7.84 X 6 X 10 ÷ 1000 = 2.68 KWH/day

West side = 5.7 X 6.08 X 6 X 10 ÷ 1000 = 2.08 KWH/day

Therefore, for daytime total heat loss $Q_{c3.1}$ = 9.04 KWH/day

For night time,

North side = 2 X 5.58 X (-8) X 10 ÷ 1000 = -0.89 KWH/day

South side = 2 X 6.96 X (-8) X 10 ÷ 1000 = -1.11 KWH/day

East side = 2 X 7.84 X (-8) X 10 ÷ 1000 = -1.25 KWH/day

West side = 2 X 6.08 X (-8) X 10 ÷ 1000 = -0.97 KWH/day

Therefore, for night time total heat loss $Q_{c3.2}$ = -4.22KWH/day

Therefore, total transmission heat loss through windows Q_{c3} = 4.82 KWH/day

- <u>Internal Loads (Q_i)</u>

Considering 2 people at day, and 4 people at night,

$$Q_p = \frac{Number\ of\ people\ X\ Number\ of\ hours\ X\ heat\ gain}{24\ hours}$$

Allow, 80W / person for active hours
40W/ person sleeping

For 4 people during night = 4 X 14 X 40 ÷ 1000 = 2.24KWH/day

For 2 people during day = 2 X 10 X 80 ÷ 1000 = 1.60 KWH/day

Allowing 24 light units at 60W and 0.75 Ω for an average of 3 hours per day

$$Q_l = \frac{Number\ of\ lights\ X\ \Omega\ X\ number\ of\ hours\ X\ rating}{24\ hours}$$

Therefore, Q_l = 24 X 0.75 X 3 X 60 ÷ 1000 = 3.24 KWH/day

For Appliances,

$$Q_a = \frac{Number\ of\ appliances\ X\ \Omega\ X\ number\ of\ hours\ X\ rating}{24\ hours}$$

Where, Ω = 0.60 for common appliances

Wattage of appliances, Stove 1 kW

Refrigerator 0.5 kW

Television 0.2 kW

Computer 0.2 kW

No. of stove = 1

No. of Refrigerator = 1

No. of Televisions = 2

No. of computers = 1

Therefore,

For stove = 1 X 0.6 X 2 X 1 = 1.2 KWH/day

For Refrigerator = 1 X 0.6 X 10 X 0.5 = 3 KWH/day

For Televisions = 2 X 0.6 X 3 X 0.2 = 0.72KWH/day

For computers = 1 X 0.6 X 3 X 0.2 = 0.36 KWH/day

Total Q_a = 5.28 KHW/day

Therefore for internal load Q_i = 12.36 KWH/day

- Ventilation loads (Q_v)

$$Q_v = 1.196\ C_v\ (t_o - t_i)$$

Where, 1.196 = Specific heat of air

$$C_v = \frac{Number\ of\ air\ changes\ per\ hour\ X\ volume\ of\ space}{3.6}$$

Here, C_v = rate of ventilation

Allowing 4 air changes per hour,

$$C_v = \frac{4\ X\ 288}{3.6} = 320$$

For daytime,

Q_{v1} = 1.196 X 320 X 6 X 10 ÷ 1000 = 22.96 KWH/day

For night time,

Q_{v2} = 1.196 X 320 X -8 X 14 ÷ 1000 = -42.86 KWH/day

Therefore, total ventilation load Q_v = -19.90

-Thermal Balance

$Q = Q_s + Q_c + Q_i + Q_v$

$Q = 61.97 + (-7.58 + (-13.18) + 4.82)) + 12.36 + (-19.90)$

Q = 43.13 KWH/day

Therefore the house is gaining heat on an average winter day.

Summer calculations:

-Solar air calculations

T_{Sa} = t_{ao} + cloud factor (a . I . R_o - e . I_r . R_o)

Where, a = 0.2 I_r = 90

T_{ao} = 35 C.F. = 0.5

e = 0.11 R_o = 0.05

I = (27 X 1000) / (3.6 X 15) = 549.5

T_{sa} = 35 + 0.5 (0.2 X 549.5 X 0.05 – 0.11 X 90 X 0.05)

= 37.5ºC

- Solar Glazing Gains Q_S

The central skylight is completely shaded.

Windows are completely shaded, so only diffused radiations have been considered here for calculating solar heat gain

North side = 0.8 X (4.60 ÷ 3.6) X 4.14 = 4.23

South side = 0.8 X (2.21 ÷ 3.6) X 5.52 = 2.71

East side = 0.8 X (2.32 ÷ 3.6) X 6.4 = 3.29

West side = 0.8 X (2.32 ÷ 3.6) X 4.64 = 2.39

Therefore, total glazing gains Q_S = 12.62 KWH/day

- <u>Roof loads</u>

For daytime,

$U = 2.43\ W/m^2K$

A = 60 sq.m.

$t_o = 35ºC$

$t_i = 27ºC$

$Q_{r1} = 2.43 \times 60 \times 8 \times 14 \div 1000$

$= 16.32$ KWH/day

For night time,

$U = 2.43\ W/m^2K$

A = 60 sq.m.

$t_o = 18ºC$

$t_i = 27ºC$

$Q_{r2} = 2.43 \times 60 \times (-9) \times 10 \div 1000$

$= -18.12$ KWH/day

Therefore <u>total roof load Q_{c1} = -1.8 KWH/day</u>

- <u>Transmission heat loss through walls</u>

For daytime, $\Delta T = 37.5 – 27 = 10.5ºC$

North side = 1.98 X 31.86 X 10.5 X 14 ÷ 1000 = 9.27

South side = 1.98 X 30.48 X 10.5 X 14 ÷ 1000 = 8.87

East side = 1.98 X 32 X 10.5 X 14 ÷ 1000 = 9.31

West side = 1.98 X 33.76 X 10.5 X 14 ÷ 1000 = 9.82

Total daytime loss = 31.27 KWH/day

For night, $\Delta T = 27 – 37.5 = -10.5^{o}C$

North side = 1.98 X 31.86 X (-10.5) X 10 ÷ 1000 = -6.62

South side = 1.98 X 30.48 X (-10.5) X 10 ÷ 1000 = -6.33

East side = 1.98 X 32 X (-10.5) X 10 ÷ 1000 = -6.65

West side = 1.98 X 33.76 X (-10.5) X 10 ÷ 1000 = -7.01

Total night time loss = -26.61 KHW/day

Therefore total transmission heat loss through walls Q_{c2} = 4.66KWH/day

- Transmission loss through windows

The "u" value will be different for day and night due to the effect of interior shading devices like curtains, blinds etc.

For daytime,

North side = 2 X 5.58 X 10.5 X 14 ÷ 1000 = 1.64

South side = 2 X 6.96 X 10.5 X 14 ÷ 1000 = 2.04

East side = 2 X 7.84 X 10.5 X 14 ÷ 1000 = 2.30

West side = 2 X 6.08 X 10.5 X 14 ÷ 1000 = 1.78

Total daytime loss = 7.76 KWH/day

For night time,

North side = 5.7 X 5.58 X (-10.5) X 10 ÷ 1000 = -5.34

South side = 5.7 X 6.96 X (-10.5) X 10 ÷ 1000 = -6.17

East side = 5.7 X 7.84 X (-10.5) X 10 ÷ 1000 = -6.70

West side = 5.7 X 6.08 X (-10.5) X 10 ÷ 1000 = -5.64

Total night time loss = -23.85 KWH/day

Therefore, total transmission loss through windows Q_{c3} = -16.09 KWH/day

- Internal loads Q_i

For 5 people during night = 4 X 10 X 40 ÷ 1000 = 1.6 KWH/day

For 2 people during day = 2 X 14 X 80÷ 1000 = 2.24 KWH/day

From winter calculations,

For lights, Q_l = 3.24 KWH/day

For appliances, Q_a = 5.28 KHW/day

Therefore, total internal loads Q_i = 12.36 KWH/day

- Ventilation loads Q_v

Allowing 4 air changes per hour

Q_{v1} = 1.196 X 320 X 10.5 X 10 ÷ 1000 = 40.18 KWH/day

Q_{v2} = 1.196 X 320 X (-10.5) X 14 ÷ 1000 = -56.25KWH/day

Therefore total ventilation loads Q_v = -16.07 KWH/day

- <u>Thermal balance</u>

$$Q = 12.62 + (-1.8 + 4.66 + (-16.09)) + 12.36 + (-16.07)$$

Therefore, $Q = -4.32$ KHW/day

Therefore, the house is losing more heat than it is gaining on a typical summer day.

But the house will perform better than shown in the calculations, as the stack effect of the skylight is not considered in the calculations.

7. Conclusion

Within the limited time frame, this dissertation has provided a general understanding of solar passive architecture and its implementation as design elements in a house in Nasik. It is shown that solar passive design saves energy by maximizing natural cooling, ventilation and lighting. Reduction in consumption of conventional energy leads to reduced utility bills and thus reducing emission of greenhouse gases. Houses with good passive design are healthier and more comfortable for its occupants.

This dissertation also hopefully will help people change their belief that a solar passive house can be aesthetically pleasing compared to a conventionally designed house. Solar passive architecture designs can create wonderful structures with the intelligent integration of passive elements which make use of solar and natural components.

In the future, more research on solar passive elements is needed to be done to improve the performance of solar housing in Nasik and also for other regions with similar culture and climate. By the implementation of these design elements, the consumption of electricity will be reduced and thereby giving the citizens of Nasik a relief from load shedding problems. These strategies will also contribute in saving our environment and reducing climate change.

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